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Ministry of
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EM-81

Provincial Highways

THE INFLUENCE OF THE ALKALI-SILICATE REACTION ON STRUCTURES IN THE VICINITY OF SUDBURY, ONTARIO

REPORT EM-81

THE INFLUENCE OF THE ALKALI-SILICATE REACTION ON STRUCTURES IN THE VICINITY OF SUDBURY, ONTARIO

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ENGINEERING MATERIALS OFFICE

SOILS AND AGGREGATES SECTION

JULY 1987

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It is recommended that reference to this document be made in the following form:

MAGNI, E. R. and ROGERS, C.A., 1987; The influence of the alkali-silicate reaction on structures in the vicinity of Sudbury, Ontario; Ontario Ministry of Transportation and Communications, Engineering Materials Office, Report EM-81.

THIS REPORT IS PUBLISHED WITHOUT PREJUDICE AS TO THE APPLICATION OF THE FINDINGS

ABSTRACT

Argillites, greywackes and quartz arenites (quartzitic sandstones) of the Huronian Supergroup are alkali-reactive in Portland cement concrete. These metamorphosed sedimentary rocks are found in Northern Ontario from Blind River through Sudbury to New Liskeard. The percentage of the reactive rock types in the gravels in the Sudbury area is between 65 and 90 percent.

Alkali reaction with these aggregates has resulted in the expansion and cracking of numerous concrete structures in the vicinity of Sudbury. Field surveys have shown that municipal, regional, provincial and crown structures have all been affected to varying degrees by alkali-aggregate reaction. Twenty-six bridge structures in the Sudbury area are affected and many sidewalks, and curb and gutter show pattern cracking. Three of the older bridge structures have been replaced as a result of deterioration promoted by the reaction. Many of the other structures require or will eventually require extensive repairs. A general relationship exists between age of concrete and severity of distress.

Petrographic examination of concrete from many of these structures confirms that cracking, rims and alkali silica gel formation are common in all elements exposed to moisture and de-icing salt (NaCl). Concrete prism expansion tests at 38°C and 100 percent humidity have confirmed the expansive nature of these aggregates.

Current Ministry of Transportation and Communications practice in the area of Ontario where these rocks are found is to conduct petrographic examination of the coarse aggregate. If the quantity of potentially reactive rock types is less than about 15 percent, the aggregate may be used in concrete without further testing.

INTRODUCTION

In the mid-sixties, Ontario Hydro noticed objectionable expansion and cracking of the Lady Evelyn Lake Dam, west of New Liskeard. An extensive study was conducted by Dolar-Mantuani (1969), which showed that the expansion was caused by argillite and greywacke in the coarse aggregate. The dam, constructed in 1925, was replaced in 1972.

In 1969, failure occurred of a steel beam over the Wanapitae River Bridge on Highway 17 east of Sudbury. Petrographic examination of the concrete by G. Woda of the Ontario Ministry of Transportation and Communications (MTC) showed that an alkali reaction, identical to that found in the Lady Evelyn Lake Dam, was taking place. As a result of this experience, a number of measures were adopted by MTC. A survey of all main Ontario highway bridges was conducted in 1969 to determine the incidence and severity of alkali-aggregate reactions. A number of reactive structures were identified in the vicinity of Sudbury, and in the 1969-1970 construction season, four bridges in Northern Region were constructed using a low-alkali cement. Thereafter no preventative measures or policies were adopted. This resulted in the continued use of alkali reactive aggregates in concrete construction until the early eighties.

Between 1982 and 1986 many of the structures originally surveyed in 1969 were re-examined together with recent structures. This paper describes the results of the survey.

GENERAL GEOLOGY

The reactive rocks are argillites, greywackes and quartz arenites (or quartzitic sandstones) of the flat-lying Huronian Supergroup which is of Middle Precambrian Age (>2160 million years). Argillite and greywacke are metamorphosed sedimentary rocks which originally had a high clay content. Their unmetamorphosed equivalents would best be described as shale and shaley siltstone. The distribution of the Huronian Supergroup is shown on Figure 1. In general, argillites and greywackes predominate to the north of Sudbury with sandstones, quartzites, quartzwackes and arkoses more common to the south and west.

Glacial movement during the Pleistocene was generally in a northeast to southwest direction and glacio-fluvial gravels containing the reactive Huronian Supergroup rocks were deposited in a corresponding northeast/southwest trending zone incorporating Sudbury. The reactive particle content of the gravels ranges from about 15 percent near Englehart to from 65 to 90 percent in the Sudbury area. The other particles found in the gravels are mainly granites, gneisses, gabbros and volcanics. These are considered non-reactive rock types.

Petrographic examinations of numerous concrete samples from structures in the vicinity of Sudbury, indicate that these gravels are free of Palaeozoic cherts. The exception to this is the gravels to the north of New Liskeard and to the northwest of Sudbury (west of Dowling) where trace amounts (<0.01 percent) of Palaeozoic chert have been observed in the fine aggregates.

METHODS OF STUDY

The problem of alkali-silicate reactivity was studied by field surveys of concrete structures as well as laboratory examination of concrete samples.

Field Surveys

Between 1982 and 1986 many of the provincial bridge structures originally surveyed in 1969 were re-examined, together with recent bridge structures in an effort to determine the incidence and severity of the alkali-aggregate reaction. Samples of the concrete were selected from the debris of recent repair work or else cores of concrete were obtained. The rating system used to describe the reaction in the concrete (eg. Minor, Moderate, Severe) is subjective and does not necessarily relate to the degree of pattern cracking. For instance, obvious pattern cracking that occurs in a four year old bridge is rated as moderate while the same degree of pattern cracking in a forty year old structure that has not needed repair would be judged as minor. The argument being that the deterioration of the four year old structure is very likely to progress to a point where repair will be needed in another fifteen to twenty years, while the forty year old structure has performed adequately and is unlikely to suffer further from alkali reactivity. The rating system is shown in Table 3.

In 1985, a survey of structures within the municipality of Sudbury was undertaken. This included municipal and regional bridges, retaining walls, sidewalks and curb and gutter. These structures were neither sampled, nor subjected to petrographic examination. However, the rating system described above was used to describe the severity of the reaction in the structures.

Laboratory Studies

Laboratory studies have been conducted by the Division of Building Research, National Research Council of Canada (NRC) and the Engineering Materials Office, MTC.

Work by NRC included petrographic studies of thin sections of the reactive rock types and concrete prism expansion tests on selected rock types and gravel samples. NRC also studied the adequacy of available test methods for predicting the problem of alkali-silicate reaction (Grattan-Bellew, 1978 and 1981).

MTC carried out petrographic examinations of the NRC prisms described above, as well as samples of concrete from selected bridge structures. These petrographic studies determined the percent reactive aggregate component and classified the occurrence of alkali-silica gel and reaction rims according to a subjective rating system outlined in Table 1.

DISCUSSION OF RESULTS

a) Laboratory Studies on Sudbury Gravels

i) Suitability of test methods

Grattan-Bellew (1981) investigated the suitability of available test methods for evaluating the expansion potential for the alkali-silicate reactive rocks of the Sudbury area. He concluded that the concrete prism test is the optimum for this suite of rocks. He found poor correlation between the expansion of rock cylinders and concrete prisms, but better results were obtained with the miniature rock prism test.

ii) Prisms containing selected rock types

The results of concrete expansion test results and petrographic studies on prisms containing selected rock types are presented in Table 1. The greatest expansion was measured in prisms containing exclusively argillite. At 38°C, 100 percent humidity and 1.08 percent Na_2O equivalent alkalies, these prisms expanded 0.22 percent at 300 days. Prisms containing greywackes expanded on average 0.11 percent, while quartz arenites were the least expansive of the reactive rock types with expansions averaging 0.07 percent. Gratten-Bellew (1978) noted a relationship between porosity, microcrystalline content and expansivity of the various rock types. He observed that the microcrystalline material consisted mainly of illite and a mixture of microcrystalline quartz similar in appearance to chert. It was also noted that the composition and microstructure of the microcrystalline material in the argillite was almost identical to that of the greywackes and arenites, confirming the petrographic continuity of the suite.

The occurrence of alkali-silica gel in all the prisms containing the different reactive rocks suggests the reaction mechanism probably involves microcrystalline quartz.

iii) Prisms containing gravels from the Sudbury area

NRC (Grattan-Bellew, 1981) conducted concrete prism expansion tests using gravels from the Airport Pits located to the northeast of Sudbury as well as material from a pit to the southeast of Sudbury. The results of these expansion tests and petrographic studies conducted by MTC on these prisms are presented in Table 2. The expansion tests were carried out on prisms containing 0.68 and 1.08 percent Na_2O equivalent alkalies and 300 g cement per cubic metre. A plot of expansion versus time for prisms containing the Airport gravel is shown in Figure 2. Expansions of 0.07 and 0.06 percent at 365 days for the two gravels respectively appear to confirm the severity of the problem observed in the field. Petrographic evidence of an alkali-aggregate reaction includes moderate to distinctive reaction rims, alkali-silica gel, and micro-cracking of aggregates and cement paste. The gravels contain from 60 to 80 percent reactive material.

b) Bridge Examinations

Twenty-six bridges in the vicinity of Sudbury are affected by an alkali-silicate reaction. These ranged in age from four to forty-six years old. These structures all showed pattern cracking to various degrees in all elements exposed to moisture and de-icing salt (NaCl).

Concrete samples from ten of these structures where studied in the laboratory. The results of this work is presented in Table 3. The Bailey Creek bridge and the Regional Road 55 bridges over the CPR and Hwy. 17 are shown in Figures 3, 4 and 5. The concrete in these bridges contained from 67 to 90 percent reactive aggregates which appeared petrographically identical to the gravels from the Airport Pits. The severity of the reaction appears to be related to age. The bridges constructed in 1938 and 1940 have been replaced. The CPR structure on Regional Road 55 constructed in 1955 has been extensively rehabilitated and petrographic studies of this concrete confirm a severe reaction including moderate to abundant gel and moderate to extensive cracking. Many other structures require or will require rehabilitation. More recent bridges show progressively less field and laboratory evidence of an alkali aggregate reaction. Despite the variety of structural design, construction methods and material content of these bridges, a relationship between severity of damage and age exists. The cracks caused by alkali reaction have provided access for moisture and de-icing salts to the concrete which has promoted further deterioration by freezing and thawing and corrosion of reinforcement.

c) Structures in the Municipality of Sudbury

A large number of concrete structures in Sudbury were examined. These included bridges, retaining walls, sidewalks, and curb and gutter. The concrete was rated according to the severity of the reaction in the field. Selected results from this field survey are presented in Table 4. Examples of these structures are shown in Figures 6 to 10.

Much of the concrete in Sudbury placed before 1975 shows pattern cracking. Structures constructed before 1965 show moderate to severe reaction and have generally required considerable maintenance. Most curb and gutter construction between 1969 and 1975 shows minor to moderate reaction. Curb

d) Other Structures containing Huronian Supergroup materials

A number of other concrete structures containing rock of the Huronian Supergroup further from Sudbury were also studied. The results of field surveys and petrographic examinations are presented in Table 5.

Concrete examined in the New Liskeard area from, for example, the Wabi Creek and Chester Creek Bridges contains from 40 to 55 percent alkali-silicate reactive aggregate. Assessing damage due to the alkali-silicate reaction is complicated by the presence of Palaeozoic chert in the fine aggregate which is responsible for an alkali-silica reaction.

Lady Evelyn Lake Dam west of New Liskeard was constructed in 1925 and replaced in 1972. The concrete contained about 80 percent alkali-silicate reactive aggregate (See Figure 11) and was severely cracked and displaced at the time of its replacement. This concrete also contained a trace of Palaezoic chert in the fine aggregate. The Maskinonge Dam north of Sudbury was built in 1926 and is still in service. It contains 87 percent alkali-silicate reactive aggregate and shows evidence of severe reaction.

The Serpent River Bridge, east of Blind River and to the southwest of Sudbury is severely cracked (See Figure 12) and has required extensive maintenance over the years. The deterioration of this structure has been compounded by freeze-thaw damage and corrosion of reinforcing steel.

REACTION MECHANISM

The term 'alkali-silicate' reaction has been formulated to distinguish this reaction from the classic alkali-silica reaction found with cherts. Other researchers (Dolar-Mantuani 1969) prefer to call it a slowly expanding alkali-silica reaction. The reaction mechanism is however poorly understood.

Gillott et al (1973) and Gillott and Swenson (1973) suggested that the mechanism involved the fine grained, strained quartz in these layer-structured rocks. Later work (Gillott, 1984) showed that the phyllosilicates respond differently to exposure to strong alkalies, including exfoliation, gel formation and in some cases strong resistance to alkaline attack.

Work by Grattan-Bellew (1978) showed that the composition and microstructure of the microcrystalline material in the argillites is almost identical to that of the quartz arenites strongly suggesting petrographic continuity for this suite of rocks as a whole. He recorded a relationship between amount of expansion and the ratio of pores to microcrystalline quartz similar in appearance to chert. He found that the greater the amount of microcrystalline material, the greater the expansion. He concluded that expansion of the concrete is due mainly to expansion of individual aggregate particles, although in one case expansion was partly attributed to the formation of alkali-silica gel. While there are similarities with the alkali-silica reaction (i.e. presence of alkali-silica gel in all prisms), the expansion of the individual rock particles suggests possible adsorption of water on previously 'dry' aluminosilicate surfaces in the microcrystalline portion of the rock.

TEST METHODS

The concrete prism expansion test is considered the most suitable method for determining potential reactivity of aggregates containing rocks of the Huronian Supergroup (Grattan-Bellew, 1981). Poor correlation was found between the expansion of rock cylinders and concrete prisms. Better results were obtained with the miniature rock prism test. Mortar bars made from these aggregates do not expand excessively. Expansion is proportional to the particle size of the aggregate; the larger the aggregate, the greater the expansion. The exception to the rule was a mortar bar containing argillite, which expanded despite the reduction in grain size.

The Canadian Standards Association has proposed a concrete prism expansion test at 38°C and 100 percent humidity to judge expansion of concrete due to this reaction. They have also tentatively suggested a maximum expansion of 0.04% at 1 year to separate deleteriously reactive aggregate from non-deleterious aggregate.

MTC currently restricts the use of these aggregates petrographically allowing a maximum of only 15 percent argillites, greywackes, quartz arenites and arkoses of the Huronian Supergroup in concrete.

CONCLUSIONS

1. A large number of concrete structures in Sudbury and vicinity were studied in the field. Most show signs of an alkali-aggregate reaction including pattern cracking and expansion. At least five structures have been replaced and many have required premature maintenance.

2. Petrographic examination of concrete from many of these structures showed evidence of reaction rims, alkali-silica gel and cracking on a microscopic scale. It is concluded that gravels of the Sudbury area that contain rocks of the Huronian Supergroup are potentially alkali-reactive and can cause deterioration of concrete.

3. Argillites give rise to greater expansion than greywackes in the concrete prism expansion test. These in turn cause more expansion than quartz-arenites.

4. There is no evidence that concrete fine aggregates produced from the Sudbury gravels are reactive.

5. Many of the structures affected by the alkali-silicate reaction have also experienced freeze-thaw damage and corrosion of reinforcing steel. It is concluded that initial cracking resulting from the alkali-aggregate reaction accelerated these other destructive mechanisms.

6. Acknowledging the fact that the structures examined vary significantly in construction method and material content, a definite relationship between age of concrete and extent of deterioration was recognized. Pattern cracking can generally be observed between 5 and 10 years after construction, significant maintenance is usually necessary after 25 years, and a number of structures have been replaced after 40 years.

7. There is a general relationship between evidence of reaction products (cracking, reactive aggregates, alkali-silica gel, and reaction rims) and the extent of deterioration of the concrete i.e. the most severely deteriorated structures contain a greater concentration of reaction products.

8. Selection of concrete aggregates in the region is currently based on petrographic examination. A maximum of only 15 percent argillites, greywackes, quartz arenites and arkoses of the Huronian Supergroup is allowed in concrete coarse aggregate. The most promising test is the concrete prism expansion test at 38°C and 100 percent humidity. A reliable maximum expansion value to separate deleterious from satisfactory aggregates has not yet been determined. Preliminary work suggests an expansion of 0.04 percent or greater at 1 year would rate aggregate as deleterious.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the provision of concrete prisms and test data by Paddy Grattan-Bellew of the Building Research Institute of the National Research Council. This study forms the basis for a paper by Magni, Rogers and Grattan-Bellew delivered at the 7th International Conference in Alkali-Aggregate Reaction in Ottawa in August 1986.

The assistance of Angelo Dagostino, Director of Engineering and Construction, City of Sudbury, is also acknowledged with thanks.

The authors wish to thank Ken Zasitko and David Howard for preparing and evaluating concrete prisms, and Nina DeRocchis for typing this report.

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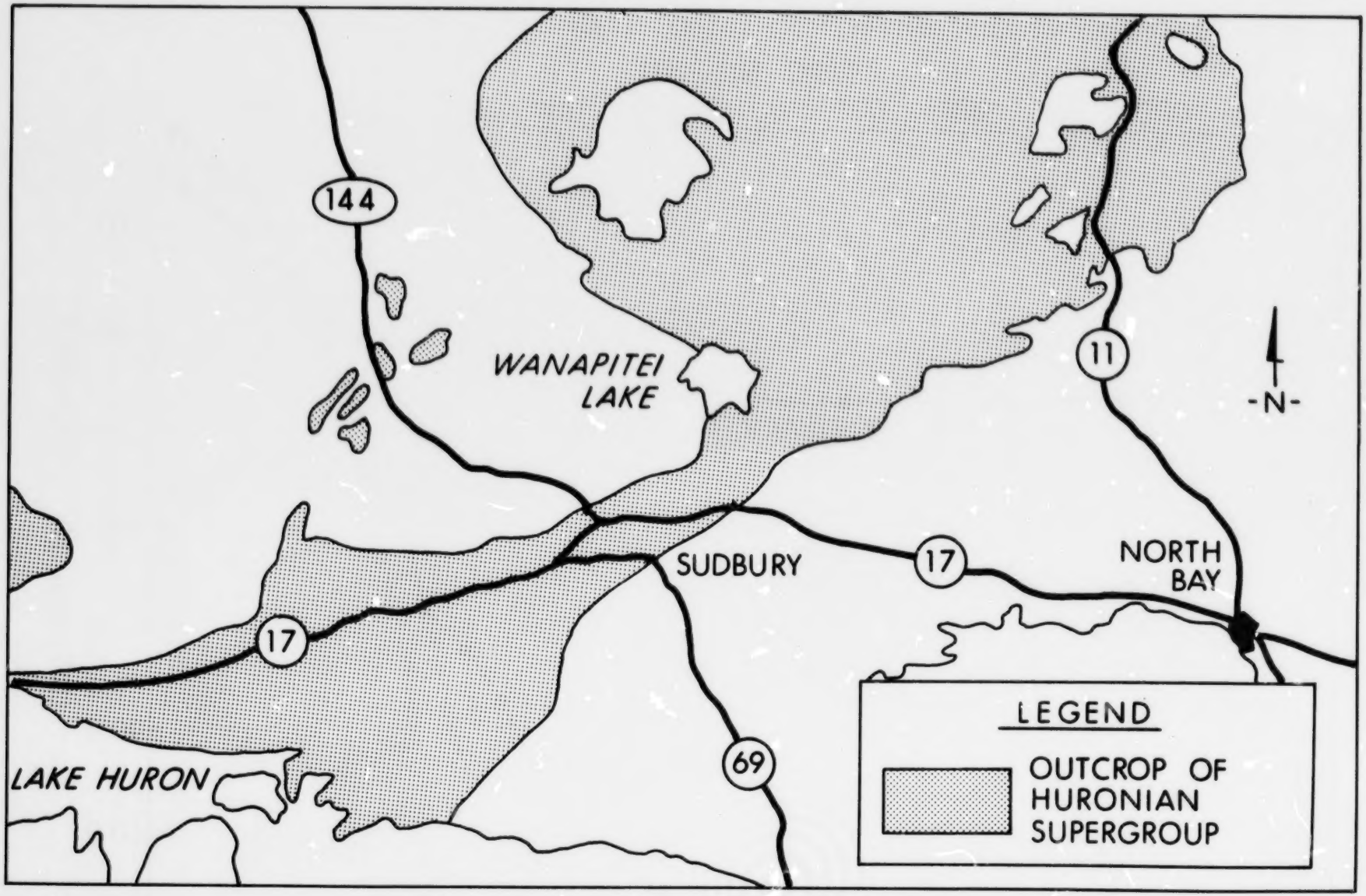

FIGURE -1 : OUTCROP OF ROCKS OF THE HURONIAN SUPERGROUP

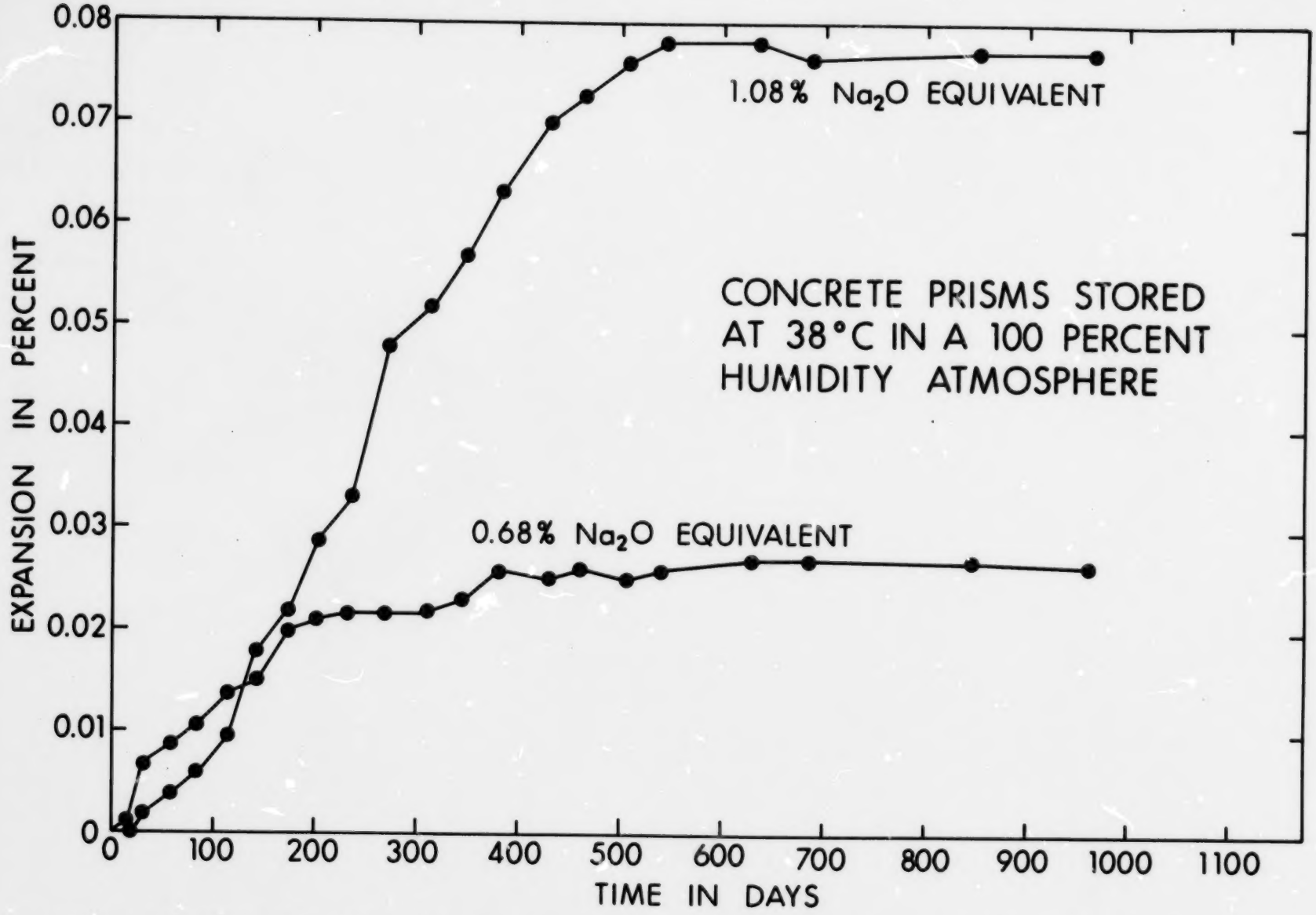

FIGURE-2: EXPANSION DATA FOR CONCRETE PRISMS CONTAINING SUDBURY AIRPORT GRAVELS.

FIGURE 3: Bailey Creek Bridge, Highway 144, northwest of Sudbury; constructed in 1967. Moderate reaction. See Table 3 #7.

FIGURE 4: Regional Road 55 (westbound) over CPR in Copper Cliff; constructed in 1955; deck extensively repaired in 1984. Severe reaction. See Table 3 #3.

FIGURE 5:

Regional Road 55 over Highway 17, Sudbury; constructed in 1980. Moderate reaction. Note appearance 4 years after construction. See Table 3 #10.

FIGURE 6: Retaining wall adjacent to Brady Street CPR Underpass; constructed in 1969. Moderate to severe reaction. See Table 4 #4.

FIGURE 7: Centre pier of College Street CPR Underpass; constructed in 1958. Moderate to severe reaction. Some severe scaling. See Table 4 #1.

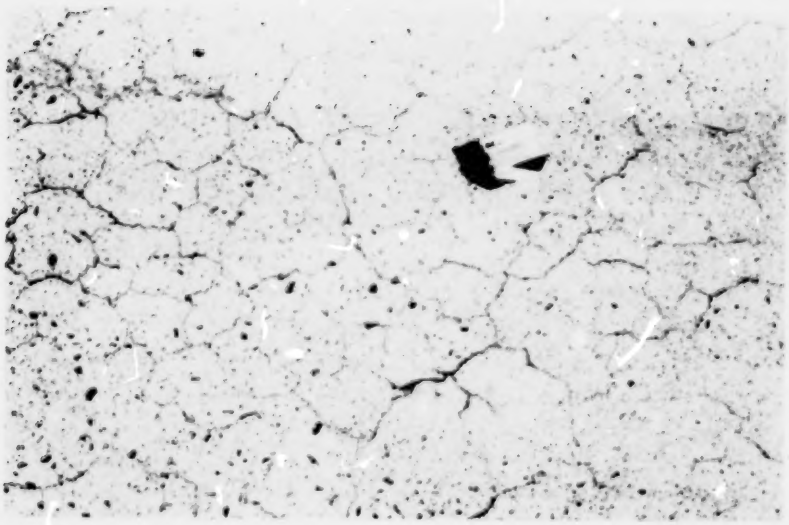

FIGURE 8: Sidewalks in front of Sudbury Community Arena and Civic Centre; constructed in 1965. See Table 4 #2.

FIGURE 9: Curb and gutter along Notre Dame Avenue from St. Annes Street to Pembroke Street; constructed in 1971. Minor reaction. See Table 4 #7.

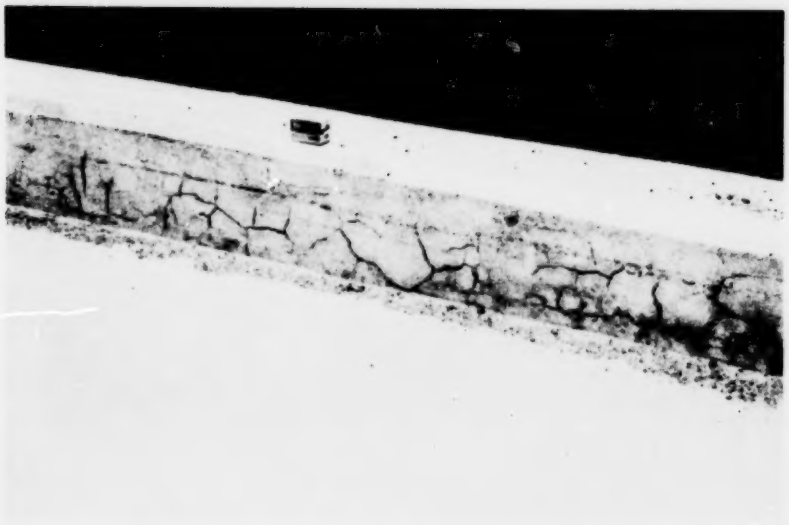

FIGURE 10: Top of retaining wall to subway crossing at corner of St. Annes Road and Notre Dame Avenue; constructed in 1971. Moderate reaction.

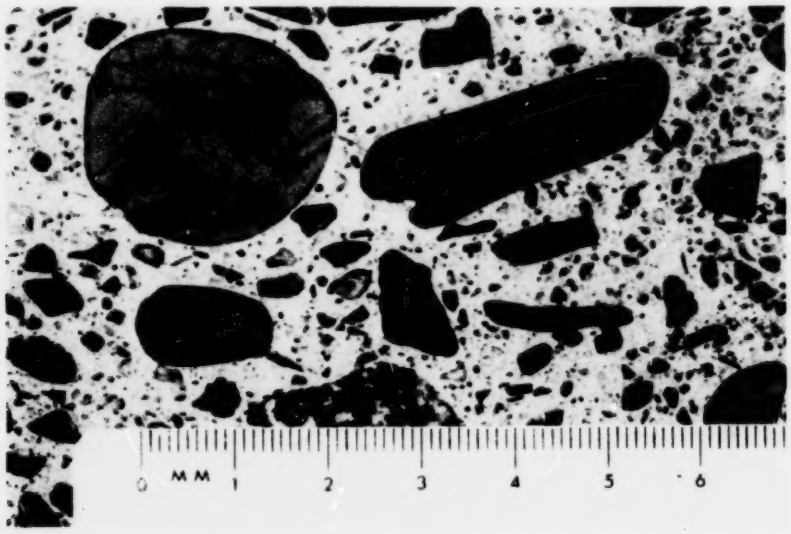

FIGURE 11: Argillite coarse aggregate in concrete from the Lady Evelyn Lake Dam; constructed 1925, replaced 1972. Note extensive microfractures and reaction rims around particles. See Table 5 #1.

FIGURE 12:

Serpent River Bridge, Highway 17, east of Blind River; constructed in 1938. Severe reaction. See Table 5 #3.

TABLE 1

SUMMARY OF EXPANSION MEASUREMENTS AND PETROGRAPHIC EXAMINATION OF CONCRETE PRISMS CONTAINING SELECTED ROCK TYPES FROM AIRPORT GRAVELS, SUDBURY

ROCK GROUP	NO. OF SAMPLES	CONCRETE PRISM EXPANSION RESULTS @ 38°C 1.08% Na_2O EQUIV. AND 300 DAYS	POROSITY (P) %	MICROCRYSTALLINE CONTENT (M) %	P/M	PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
Argillite	1	0.219	0.82	82	0.01	Faint reaction rims; moderate gel; extensive, continuous cracks
Greywacke	4	0.93 - 0.136 (0.112)*	0.97 - 1.05 (1.11)	52 - 71 (61)	0.02 - 0.02 (0.02)	Faint reaction rims; minor to moderate gel; extensive continuous cracks
Quartz Arenite (Quartzitic Sandstone)	8	0.018 - 0.110 (0.069)	0.67 - 3.80 (1.65)	2 - 31 (16)	0.04 - 0.55 (0.16)	Moderate to distinctive reaction rims; minor to moderate gel; minor to moderate, continuous and non-continuous cracks
Other (eg. granophyre and gabbro)	2	0.009 - 0.013 (0.011)	-	-	-	No rims; no gel; minor, non-continuous cracks

* (0.112) = average of test results

LEGEND FOR PETROGRAPHIC OBSERVATIONS

CRACKING - extensive (most particles)
- moderate (half particles)
- minor (1-5% particles cracked)

GEL - abundant (filling most voids)
- moderate (filling half voids)
- minor (filling 1 to 2% of voids)

TABLE 2

SUMMARY OF EXPANSION MEASUREMENTS AND PETROGRAPHIC EXAMINATION OF CONCRETE PRISMS CONTAINING AIRPORT GRAVELS, SUDBURY

SOURCE	ALKALI CONTENT % Na_2O EQUIV. (CEMENT CONTENT = 300 gm/m^3)	CONCRETE PRISMS EXPANSION RESULTS @ 38°C			PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE				
					REACTIVE			NON-REACTIVE	EVIDENCE OF ALKALI-AGGREGATE REACTION
		168 d	365 d	1000 d	GREYWACKE, ARGILLITE (%)	QUARTZ-ARENITE (%)	TOTAL (%)	GRANITE, GABBRO, VOLCANIC (%)	
AIRPORT GRAVEL PITS, NORTHEAST OF SUDBURY	0.68	0.014	0.022	0.025	45	34	79	21	Moderate to distinctive reaction rims on white and yellow quartz-arenites and greywackes; very minor gel; minor, non-continuous cracks.
	1.08	0.018	0.070	0.081	40	30	70	30	Distinctive reaction rims on greywackes and white quartz arenites; moderate to abundant gel; extensive, continuous cracking in greywackes and quartz-arenites.
GRAVEL PITS, EAST OF SUDBURY	0.68	0.013	0.016	0.020	34	23	57	43	Minor reaction rims on greywackes and white quartz arenites; minor gel; minor cracks in greywackes and quartz-arenites.
	1.08	0.019	0.059	0.063	29	32	61	39	Minor to moderate reaction rims on greywackes, and white and yellow quartz-arenites; minor gel; minor cracks in greywackes and yellow and white quartz-arenites.

LEGEND

Petrographic Observations (see Table 1)

TABLE 3

RESULTS OF FIELD SURVEY AND PETROGRAPHIC EXAMINATION OF CONCRETE FROM BRIDGE STRUCTURES IN THE VICINITY OF SUDBURY

SITE	STRUCTURE	YEAR	FIELD OBSERVATIONS		PETROGRAPHIC EXAMINATION	
			SEVERITY OF REACTION	COMMENTS	% REACTIVE AGGREGATE	PETROGRAPHIC OBSERVATIONS
1	Veuve River Br., Hwy. 17	1938	Severe	Bridge replaced in 1970	76	Moderate reaction rims; moderate gel; minor cracks
2	Wanapitae River Br., (Old Bridge), Hwy. 17	1940	Severe	Bridge replaced in 1974	90	Moderate reaction rims; abundant gel; moderate cracks
3	CPR Br., RR 55	1955	Severe	50% of deck replaced in 1984	72	Distinctive reaction rims; abundant gel; extensive cracks
4	Wanapitae River Br., Hwy. 69	1956	Minor	-	81	Moderate reaction rims; minor gel; moderate, continuous cracks
5	Vermillion River Br., Hwy. 144	1959	Minor	-	83	Minor reaction rims; minor gel; one crack
6	Witson River Br., RR 15	1967	Moderate	-	67	Moderate reaction rims; minor gel; moderate cracks
7	Bailey Creek Br., Hwy. 144	1967	Moderate	-	68	Moderate reaction rims; minor gel; minor cracks
8	Junction Creek Br., Sudbury S.W. Bypass	1973	Moderate	-	72	Moderate reaction rims; minor gel; minor cracks
9	Wanapitae River Br., (New Bridge), Hwy. 17	1974	None	-	70	Minor reaction rims; no gel; minor cracks
10	RR 55, Hwy. 17	1980	Moderate	East bound structure	72	Minor reaction rims; minor gel; minor cracks

LEGEND: Evidence of Reaction in Field

None - No pattern cracking observed at time of field visit.
Minor - Pattern cracking observed but judged not likely to increase maintenance costs or reduce life.
Moderate - Pattern cracking observed and judged likely to eventually result in increased maintenance costs or reduced life.
Severe - Pattern cracking observed and currently causing or has caused need for maintenance and reduced life.

Petrographic Observations - For Legend see Table 1.

TABLE 4
RESULTS OF FIELD SURVEY OF CONCRETE STRUCTURES SHOWING ALKALI-AGGREGATE REACTION IN THE CITY OF SUDBURY
(Structures reported in this table are only a selection of those surveyed.)

STRUCTURE AND LOCATION	YEAR	SEVERITY OF REACTION	COMMENTS
1. CPR underpass, College Street, bridge and retaining walls	1958	Moderate to severe	Uniform pattern cracking on structure; some severe scaling and damage to south pier
2. Sidewalks in front of Sudbury Community Arena and Civic Centre	1965	Minor to moderate	Universal pattern cracking, more pronounced towards road
3. Retaining wall at corner of MacKenzie and Elgin Streets	Mid 1960's	Minor	Most pronounced pattern cracking at base of wall due to greater exposure to salt
4. CPR underpass, Brady Street, bridge and retaining walls	1969	Moderate to severe	Considerable maintenance work has been necessary on this structure; severe cracking and spalling; extensive rehabilitation in 1986
5. Curb and gutter, Regent Street south of York Street	1969	Minor to moderate	Fairly uniform pattern cracking throughout
6. Curb and gutter, Regent and Walford Street intersection	Late 1960's	Moderate	All round intersection
7. Curb and gutter, Notre Dame Ave., St. Annes Road to Pembroke Street	1971	Minor	Uniform pattern cracking all along curb. Particularly pronounced in northern curb of median
8. Median curb and gutter, Notre Dame Ave., north of Pembroke Street	1971	Moderate	Uniform pronounced pattern cracking along curb
9. Curb and gutter and low walls around old subway crossing, corner of Notre Dame Ave. and St. Annes Road	1971	Moderate	Uniform pattern cracking
10. Curb and gutter, St. Annes Road between Notre Dame Ave. and Elgin Street	1972	Minor	Uniform pattern cracking

LEGEND
Evidence of Reaction in Field (see Table 3)
Petrographic Observations (see Table 1)

TABLE 5

RESULTS OF FIELD SURVEY AND PETROGRAPHIC EXAMINATION ON CONCRETE
FROM OTHER SELECTED STRUCTURES CONTAINING REACTIVE HURONIAN SUPERGROUP ROCKS

SITE	STRUCTURE	YEAR	FIELD OBSERVATIONS		PETROGRAPHIC EXAMINATION	
			SEVERITY OF REACTION	COMMENTS	% REACTIVE AGGREGATE	PETROGRAPHIC OBSERVATIONS
1	Lady Evelyn Lake Dam, west of New Liskeard	1925	Severe	Severe cracking and displacement; dam replaced in 1972	81	Distinctive reaction rims; minor gel; extensive cracking; trace of Palaeozoic chert present
2	Maskinonge Dam northeast of Sudbury	1926	Severe	Still in service	87	Distinctive reaction rims; minor gel; moderate cracking
3	Serpent River Bridge Hwy. 17, east of Blind River	1938	Severe	Extensive cracking and deterioration	91	Distinctive reaction rims; moderate gel; moderate cracking
4	Montreal River Br., Hwy. 11, Latchford	1959	Moderate	-	52	Moderate reaction rims; moderate gel; moderate cracking
5	CPR Overhead, Hwy. 6, South of McKerrow	1960	Moderate	-	79	Faint reaction rims; abundant gel; minor cracking
6	Wabi Creek Br., Hwy. 11B, New Liskeard	1969	Moderate	-	43	Faint rims; no gel; minor cracking
7	Chester Creek Br.	1973	Minor	-	52	Faint rims; no gel; minor cracking; minor fine chert